Metaphors of Instrumental Computer Use: A Case Study

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METAPHORS OF INSTRUMENTAL COMPUTER USE: A CASE STUDY

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ABSTRACT

There are two metaphors for describing instrumental computer use: the computer as a tool, and a more comprehensive package metaphor that emphasizes all aspects of computer use (hardware, software, and social interactions with vendors and other actors in the computing world). Whereas the tool view of computing is concerned with the direct costs of hardware and software, the package view helps one estimate all costs -- social and technical -- of instrumental computer use. Data from a case study of two research laboratories that used computers for data collection provides empirical support for a package metaphor.

key words and phrases: computing package, social impacts of computing, laboratory computing, instrumental computing.

1.0 INTRODUCTION

In recent years, digital computers have become very useful in research laboratories. In this paper, we will analyze some of the social impacts of computers on the laboratories that use them.

The prevailing view of computers in laboratories is that they are nothing more than very sophisticated instruments, capable of replacing standard laboratory instruments. Computers are used because they work much faster and more accurately than the standard instruments that they replace. This viewpoint, the <u>tool</u> view of computing, makes it very hard for researchers to assess the impacts of computer use in their laboratories.

An alternative perspective for examining the use of computers in a particular setting, the <u>package</u> view, treats computing as a complex entity composed of hardware, software, programmers, users, vendors, management practices, and beliefs about computing.

It is the thesis of this paper that laboratory researchers should consider the entire package of computing when deciding whether or not to purchase a computer system, or in choosing among alternative systems. Whereas the computer-as-tool analysis is concerned mostly with hardware (monetary) costs, a package analysis also takes into account intangibles such as time, effort, and social interactions required to use the system. In other words, an understanding of the computing package helps one estimate all costs -- social and technological -- of computer use, as opposed to simply the direct costs of software development and equipment.

The computing package has been used by Kling, Scacchi, and Crabtree [KSC78], and by Kling and Scacchi [KS79], to describe instrumental computer use in general. Gasser and Scacchi use a package analysis in a paper on the social issues of personal computing [GS79].

The present paper employs a package analysis to analyze data collected in a case study of computer use in a specific setting. The data was obtained from participant observation of two laboratories between 1971 and 1976.

The first part of the paper examines the tool and package metaphors in more detail. The next section describes two laboratories that used computers for data collection and data analysis. Following that is a discussion of some problems these laboratories encountered in their use of computers; it will be shown that a package viewpoint helps one understand problematic aspects of computer use in laboratories in a way that the tool view does not.

2.0 METAPHORS FOR DESCRIBING COMPUTER USE

A research laboratory is often a small organization. It has its own set of goals, a hierarchy of personnel (e.g., a principal investigator, graduate students, undergraduate assistants, clerical personnel, etc.), and a set of procedures and tools used for achieving the goals.

The tool view of instrumental computer use is that one can replace one or more of the organization's tools with a computer system. The rationale is that computers are faster, more accurate, and more flexible than the instruments or procedures they replace. For example, a laboratory that records electrical signals such as EEG's might replace strip chart recorders with a computer system in order to more easily analyze the data. The computer could measure peak to peak intervals, or look for certain patterns in the data, etc.

An example of the pervasiveness of this tool metaphor can be seen in Finkel's handbook on instrumental computer use in research laboratories. He writes

> "computer aided experimentation results in 'better science' when properly applied because the scientist is relieved of tedious, repetetive jobs, thus permitting him more time for creative work . . . It is certain that better science will be based more and more on effective utilization of this tool." [F75, introduction]

The emphasis is on replacing existing instruments with a computer in order to gain larger quantities of data at higher rates and with increased precision.

The major advantage of computers over standard instruments, however, is that computers have the ability to "make adjustments on line in real time in response to the direction the experiment is taking" [F75, p. vii]. In other words, it is now possible to design and carry out experiments that would be practically impossible without the use of a computer.

This last idea was examined by Conery, Smith, and Russo [CSR74], where the methodology used in two cognitive psychology experiments is presented. Neither of these experiments could have been conducted without the use of an on-line computer.

The package metaphor of computing is based on the observation that computer systems are in fact the center of a large and complex industry and social system which is known as "the computing world" [KG78]. This means that any organization that decides to use a computer system also decides to interact with the computing world, a world that is made up of a myriad of complicated pieces of hardware, as well as salesmen, programmers, hardware maintenance personnel, and many other organizations. Furthermore, the computer-using organization must deal, either directly or indirectly, with concepts outside its own discipline, concepts such as software engineering, reliability, applicability, and other more abstract components of the computing world. Another very important aspect of the computing world is the set of perceptions of computing held by people outside the computing world, people such as researchers, lab assistants, and (as we shall see) subjects in psychology experiments.

It is this large and complex ensemble that is known as the <u>computing package</u>:

> "not only hardware and software facilities, but also a diverse set of skills, organizational units to supply and maintain services and data, and sets of beliefs about what computing is good for and how it may be used efficaciously" [KS79, p.108].

The components of the computing package that are relevent to this paper are summarized in figure 1.

3.0 THE LABORATORIES

This section is a description of two research laboratories and some of the experiments that they performed. The next section will analyze some of the problems these laboratories encountered in the use of their systems.

These laboratories both owned PDP-12 computers, which were manufactured by the Digital Equipment Corporation (DEC). The PDP-12 is a minicomputer that can operate in either of two modes. In one mode, it is essentially a PDP-8/i; in the other, it is a LINC-8 (both of these machines are also DEC products). The machines owned by the laboratories had from 8K to 12K of 12-bit words for main memory, two LINCtape drives, a teletype, and no disks. These machines cost approximately $100,000 at the time they were purchased in the late 60's.

Figure 1

Components of the Computing Package

(adapted from Gasser and Scacchi [GS79])

1. hardware -- processors, mass storage devices, hardcopy devices, special lab equipment interfaced to the computer.

2. software -- user-written software for data collection, vendor-supplied application programs and operating systems (file systems, program development and maintenance tools).

3. time -- required for learning how to use a system, to develop special applications, to install "imported" software, to maintain existing hardware and software.

4. money -- for new systems, maintenance and upgrading of existing systems.

5. inducements -- use of a new research "tool," ability to design more sophisticated experiments.

6. skill -- developing new software for data collection, designing experiments that utilize on-line computers, operating the computer, maintaining the hardware and software, dealing with vendors.

7. recurring social interactions -- negotiations between laboratory personnel and outside organizations, computer education for laboratory personnel, interactions between system programmers and researchers, computer mediated interactions between subjects and experimenters.

8. organizational support -- maintenance, research grants, educational.

9. beliefs -- about how computing can be used, about what computers should be used for, conceptions/misconceptions about what computers can do.

10. reverse adaptation -- the tendency to change a problem to fit the means available for solving it (in this case the means is a computer system).

3.1 Psychology Department

One research group, part of the Psychology Department of a major West Coast university, studied choice and decision making, and other cognitive processes. In this group's experiments, subjects were presented with a visual display for some task; then the subjects' eye movements were monitored as they performed that task. For example, in one decision making experiment, a subject would see the description of eight used cars, and choose the one he or she thought was the best car.

The computer system was used to display the stimuli, and to record the subjects' eye movements and reduce them to a sequence of fixations. Each element in the fixation sequence was a pair made up of the stimulus (e.g., a car) that was fixated, and how long the subject looked at it.

The members of the research group during this period included the principal investigator (a faculty member), two graduate students, and up to four part time undergraduate research assistants. The duties of the research assistants included developing software for data collection on the PDP-12 and data analysis on the campus computer center's Burroughs B6700.

There were two experiments conducted during this time in which the computer was used for more than simply recording eye movements.

In one, called the <u>prompted protocol</u> experiment, the computer would record a sequence of fixations when the subject was making a decision. After the decision was made, the computer would "replay" the sequence for the subject by moving a marker over the alternatives to show the subjects the order in which they looked at the alternatives and how long each fixation was. The replay was used to prompt the subject's verbal protocol, or description of the decision process; when the marker was over a particular alternative, the experimenter would ask the subject why he looked where he did.

This experiment was designed to establish a new method for collecting verbal protocols, since it was felt that traditional methods of collecting verbal protocols make the protocols unreliable. One of the traditional methods (which was used by Newell and Simon in their cryptarithmetic experiments [NS72]) is to have a subject explain the process as it is being performed; this greatly disrupts the process being investigated, since the subject is trying to describe how he is making his decision as the decision is being made.

A second traditional method, the retrospective protocol, is to have the subject try to remember how the task was performed after it is done; this method suffers from lack of detail and the subject's less than perfect recall.

The prompted protocol was designed to avoid the shortcomings of the two traditional methods by allowing the subject to complete the task without any interruptions, and then using a prompt to extract a more accurate retrospective protocol.

The second noteworthy experiment was a successor of the prompted protocol experiment. In this project, which was called the <u>altered sequence</u> experiment, the computer would replay a slightly modified sequence of fixations instead of the original sequence. This experiment was designed to detect what Newell and Simon call cognitive episodes. For example, in decision making experiments, subjects were often observed to generate a subsequence of fixations on only two alternatives; it was postulated that this "back and forth" pattern was a comparison of the two alternatives. These comparisons are examples of cognitive episodes.

The altered sequence experiment was based on the assumption that if the modifications to the sequence broke up an episode (e.g., if the new sequence showed two different alternatives being compared), the subject would notice it and say something about it in the (prompted) verbal protocol. If the modification did not alter an episode (e.g., if an extra fixation was added to the end of a comparison) the subject would not notice it.

3.2 Phonetics Lab

The Phonetics Lab used a PDP-12 to record and analyze EEG's in evoked potential experiments, and to generate linguistic stimuli for evoked potential and other phonetics experiments. (In evoked potential experiments, the subject's EEG is measured over a period that starts when the stimulus starts, and ends 500 milliseconds later.) The personnel in this laboratory consisted of the principal investigator, a postdoctoral researcher, four graduate students, and two technically oriented half time research assistants (one programmer and one electronics expert).

In the Phonetics Lab, the computer was generally used as an expensive replacement for more conventional laboratory equipment; for example, the stimuli could just as easily have been generated by an audio tape recorder. The one exception was a signal averaging program that took advantage of the fact that the computer could store a large amount of EEG data before analyzing it. Most signal averaging techniques ignore data until a trigger pulse is generated, and then start recording the EEG. The computer was able to store the EEG data, and when the trigger pulse was detected, go back and get the EEG data from the previous few milliseconds. In this way EEG's that occured before the onset of the stimulus could be analyzed.

4.0 PROBLEMS WITH THE COMPUTING PACKAGE

Four aspects of computer use that were problematic for the laboratories will be discussed in this section. Two of the problems are described and then analyzed using both the tool and package metaphors. The other two problems are presented as illustrations of two of the components of the computing package.

4.1 Disks

The only file-oriented mass storage devices on these systems were LINCtapes (small block-oriented magnetic tapes). This meant that the operating system software, especially the file system, was very slow, because of the time required to access information in tape files. This in turn made software development very tedious. Furthermore, the file system was so awkward that backup copies of files were not made as frequently as they should have been, and much time was lost when tape files were lost. The net result of all this was that an inordinate amount of computer time was devoted to software development, as opposed to running experiments.

Both laboratories requested funds in grant proposals in order to purchase disks. The granting agencies denied the requests, and in each case argued that a disk would not improve the system's capability in performing its "main function," data collection.

This is a clear example of a tool view of computing, where a computer system is perceived as nothing more than a replacement for existing laboratory instruments. It also illustrates how a package analysis of a laboratory and its computer system would have shown that (in the long run) a disk is indeed necessary to help the system collect data, since a system with a disk would facilitate software development and therefore allow the laboratory to use more computer time for data collection. This situation also shows that management practice, one of the elements of the computing package (figure 1), is as much of a factor in determining the capabilities of a system as the availability of computer hardware.

4.2 Hardware Maintenance

When any organization acquires a computer system, it will also have to acquire some method of maintaining the system hardware. For most laboratories, as well as for other small organizations that have relatively small computer systems, it is not practical to train a staff member to repair and maintain computer hardware in addition to his or her other duties, nor is it feasible to hire an additional staff member who already has the needed skills. The only alternative in these cases is to enter into a maintenance contract with an outside agency. Both the Psychology Lab and the Phonetics Lab had maintenance contracts with the local DEC field office. Though one of the members of the Phonetics Lab was a highly skilled electronics technician, maintenance of the computer system was outside the scope of his field of expertise. He repaired existing instruments, and designed new instruments, but these were all traditional analog devices.

One of the ramifications of the maintenance contract arrangement is the fact that each laboratory was forced to interact with a separate organization, an organization with priorities and goals which were not always compatible with those of the laboratory. This is a much more complicated and problematic arrangement than having a member of the laboratory in charge of hardware maintenance, since such a member is more easily constrained by the laboratory.

What follows is an example of such a conflict of priorities between the laboratories and the service organization. Each laboratory experienced similar problems with maintenance.

In the early 1970's, PDP-8's and PDP-12's made up a large fraction of the machines serviced by the DEC field service organization, and universities that owned these machines were major customers of DEC. In subsequent years the newer PDP-11 replaced the older machines as the most common machine; at the same time, non-university customers became more important sources of revenue for DEC. Many of the new customers had many systems at one location, and full-time assignment to one of these locations became a preferred assignment for the DEC field service personnel. These assignments were given to the senior members of the field service organization, the same people who had been maintaining the laboratories' systems. As a consequence, the newer field service personnel that visited the laboratories during the latter part of the period of this study tended to be less experienced, less skilled, and less familiar with the laboratories and the manner in which they used their computers.

4.3 "The Computer Is Always Right"

One of the components of the computing package is beliefs about computing (figure 1). An example of such a belief is the trust in the accuracy of the measurements the computer was providing. The degree of trust varied across individuals and situations. After the software and hardware was operational for over a year, all members of the Psychology Lab believed that the sequences of fixations recorded during eye movement experiments were accurate. This confidence was transmitted to the subjects in the prompted protocol and altered sequence experiments.

When the altered sequence experiment was originally designed, the experimenters decided not to tell the subjects in advance that some of the sequences would be modified before being replayed (this decision was made because the experimenters did not want to prejudice the verbal protocols in any manner). However, after the first few sessions, it was observed that the subjects were not reporting any alterations in the replayed sequences. If they noticed anything peculiar about a replay, they thought that they had forgotten part of the decision process that they had just performed. To remedy this situation, in subsequent sessions the subjects were informed at the beginning of the session that the computer would be altering some fixation sequences before replaying them. After this adjustment, subjects started identifying alterations to the fixation sequence.

To summarize, the subjects' beliefs about computing (e.g., the accuracy of the computer's measurements) interfered with the design of an experiment.

One can only speculate about what would have happened if the subjects were not aware of the fact that a computer system was being used to control the experiment, if instead they were told that a human experimenter was using a video tape machine to record the eye movements and was generating a replay manually. Subjects may have been more inclined to believe that the human experimenter had made a mistake in generating a replay, thus obviating the need to modify the design of the experiment.

4.4 Reverse Adaptation

The traditional concept of the use of tools is that an individual has a job to perform, and a selection of various tools available to help do the job, i.e., it is possible to "choose the right tool for the job."

Winner [W77] argues that this choice is no longer possible when the tools are the products of advanced technology, since these tools are too complicated and expensive. It is more likely that a person who has invested heavily in a particular technology will modify jobs so that the jobs can be performed with the existing tools. Reverse adaptation is this modification of "ends" to fit the "means."

The modification of the altered sequence experiment, described in the previous section, is an example of reverse adaptation in the Psychology Lab: the experimenters modified their experiment in order to use their instrumental computer system.

Another example of reverse adaptation occured in the Phonetics Lab. This laboratory wanted to run some experiments which depended upon having a fast Fourier transform (FFT) program working on their system. They were able to obtain such a program from DECUS, an organization of users of DEC systems that maintains a library of programs written by users. However, this program was written to run on a PDP-8, and the laboratory could not get it to work properly on their PDP-12 (recall that in one mode, the PDP-12 operates like a PDP-8/i). The experiments had to be abandoned, since it would have taken too much time and money to figure out why this particular FFT program wasn't working. The laboratory, at this point in time, had invested its limited resources (time, money, and skill) in its own sophisticated computing "tool." This investment in a particular package constrained the choice of experiments that could or could not be done.

5.0 CONCLUSION

Empirical data from a case study of computer use and its effects in two laboratories indicates that a computing package is a viable perspective for examining instrumental computing. If one thinks of computers as nothing more than sophisticated tools, then phenomena such as reverse adaptation, problematic interactions with vendors and service agencies, and schedule delays due to difficulties in software development will be seen as "side effects" of instrumental computing, meaning these phenomena are random, unforeseeable events. On the other hand, when computing is examined and described as a package, such phenomena are seen to be more predictable consequences of the decision to replace standard instruments with computer systems.

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The package metaphor of instrumental computer use has been used by Kling, Scacchi, and Crabtree [KSC78], Kling and Scacchi [KS79], and Gasser and Scacchi [GS79] to describe the use of computers in settings other than research laboratories. This paper could not have been written without many fruitful discussions with Rob Kling, Les Gasser, and Walt Scacchi.

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